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XXVI. Technical Facilities

FACILITIES OFFICE

A. Variable Optical Techniques Applied to Solar Simulators, *M. N. Wilson and R. R. Beal*

1. Introduction

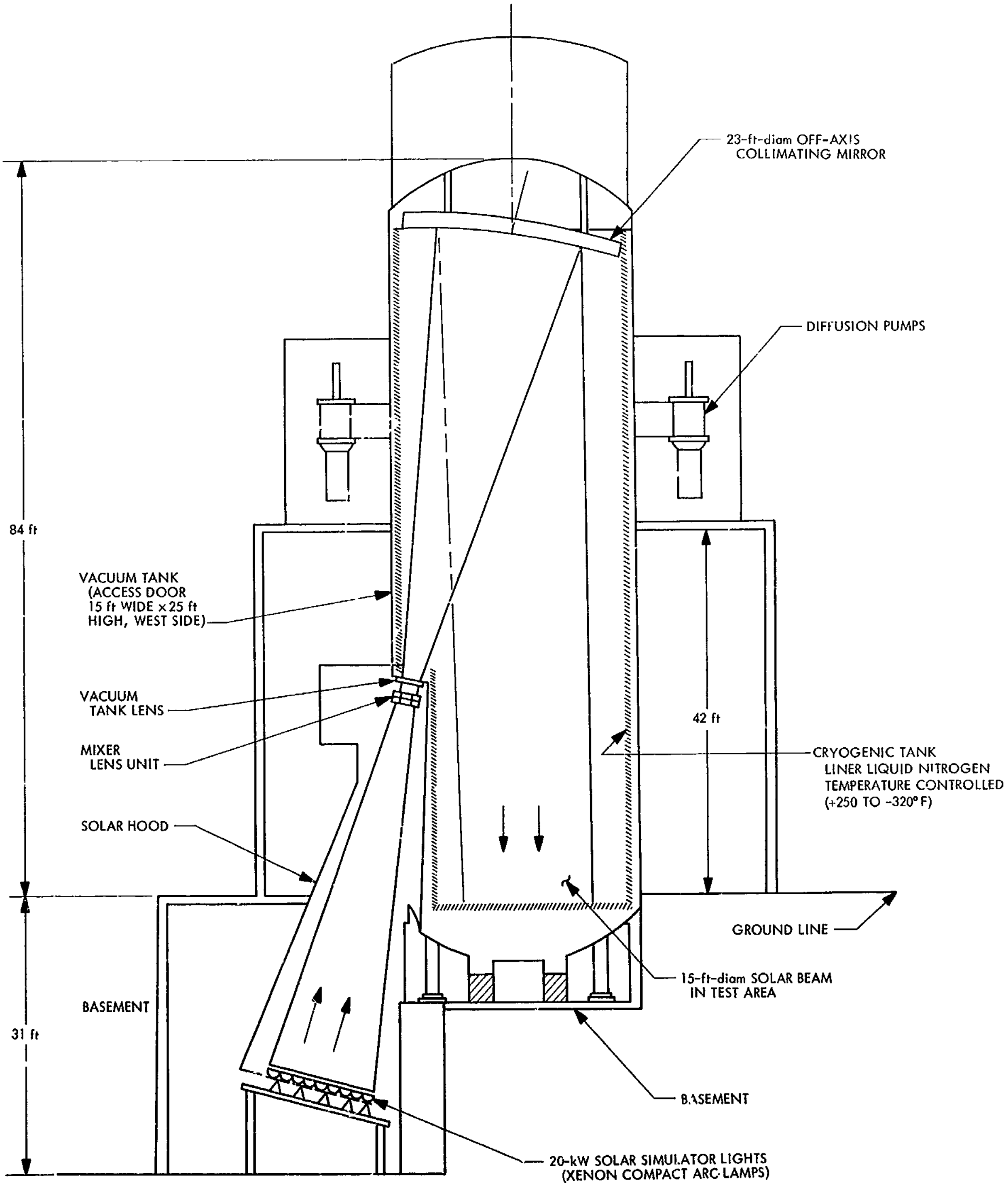
The extensive modifications to the 25-ft space chamber at JPL, performed during 1966 and 1967, resulted in the creation of a solar simulation scheme that was capable of producing a uniform (±5%), well-collimated (±1 deg) beam of radiant energy on a 15-ft-diam circle within the 25-ft test volume of the space simulator. This system drew upon the experience gained from the earlier JPL 10-ft simulator optical system and used as a source the brightest xenon compact arc lamps (20 kW) that were then available.

In view of past optimism and general experimental unknowns regarding bulb performance, a very conservative design approach was adopted that resulted in the system actually being capable of producing 290 W/ft^2 (with no reserve) or an operational level of about 175–190 W/ft^2 over a 15.5-ft-diam by 25-ft-high test volume.

2. Design and Characteristics

The 37 20-kW xenon compact arc lamp energy sources (Fig. 1) are arranged in a hexagonal pattern in the lamp basement and project, via 27-in. hyperbolic reflectors, the resultant radiant energy onto the front face of the optical mixer elements in a typical gaussian distribution. The front face of the mixer consists of 19 circular lenses and is followed by a second plane of 19 hexagonal lenses. Both are closely packed and together provide 19 parallel but separate light paths through the optical mixer.

Each path is at a slightly different skew angle with respect to the optical axis of the system so a slight amount of power is required at the penetration window to cause the 19 systems to superimpose in the test volume, thus minimizing skirt effects and contributing to the system efficiency. The optical mixer, or integrator, is the essential component that causes the images to superimpose, thereby averaging the various energy contributions of each of the 19 paths so as to produce a single uniform beam. A



CROSS SECTION (LOOKING EAST)
NOT TO SCALE

Fig. 1. Existing 15-ft-diam earth-intensity sun of 25-ft space simulator

detailed explanation of the optical mixer principle is given in Ref. 1.

The 23-ft temperature-controlled mirror in the top of the vessel serves to reverse the direction of the projected light beam and produces parallel (± 1 deg) rays since the mixer, or source of the incident light, is located approximately at the focal point of the mirror. The 23-ft size was selected to handle a future 20-ft beam if it were ever installed in the simulator. Room was also provided in the basement for 24 additional lights should the increased energy for a larger beam be required.

The present 37 20-kW xenon compact arc lamps, when in a "new" condition, will produce 290 W/ft^2 maximum over a 15.5-ft-diam circle. Since the images of all 37 lamps are superimposed at the mixer face, it is clearly possible to reduce beam intensity by either turning off individual bulbs or reducing power levels until the desired intensity is reached. It should be noted, however, that these actions do not change the uniformity, collimation, size, or any other geometric characteristic of the beam. Only the intensity is affected. Thus, the existing system could, potentially, simulate solar radiation rather accurately from near Venus intensity to essentially zero intensity.

The system is rather sensitive to the spacing between the mixer lens elements. The image of the lamp bank is (nominally) contained within the second lens. If these lenses are separated further, this image overfills the second lens and energy is lost; i.e., a portion of the energy of the source is projected as a smaller beam of the same intensity. If these lenses are brought nearer to each other, the image-forming rays of the lamps remain within the second lens but the projected beam size is rapidly increased with resulting loss in maximum intensity. Second order effects, resulting from lens adjustment, are also important as regard changes in uniformity and skirt losses. Thus, for all practical purposes, the system is essentially one of fixed geometrical characteristics. Only major physical changes to the simulator can produce beam sizes other than that of the basic design size.

The capacity of the JPL 25-ft space simulator is such that it can physically and thermally accommodate a 20-ft spacecraft, should it be required. Also, several potential missions have been considered in which the *Titan* is used as a launch vehicle, utilizing its 10-ft-diam shroud. The optimum optical system, then, was one that could cover, without change, this 10- to 20-ft range, with up to Mercury intensity (900 W/ft^2) on the smaller size. Simple area-intensity calculations suggest that sufficient power is available but techniques to produce the desired results had not been developed.

The operational usefulness of the simulator could be increased many fold if extensive modifications were not required for each different test requirement but, instead, a simple remote optical adjustment could be accomplished.

3. Studies

A study[1] was made to investigate the limitations and possible changes to the mixer–projection system to see if a favorable solution was feasible.

It was determined early in the work that systems of 3- or 4-lens mixers offered no advantage over a 2-lens system, that all were essentially fixed geometry systems, and that within reasonable bounds of performance the mixer could not be increased in physical size. The conclusion, as related to the present optical system, is that it cannot be made to reduce the diameter of the projected beam of light while increasing its intensity proportionally.

Later work incorporated additional lenses in the optical path just behind a relocated mixer–integrator so as to take advantage of the 40-in.-diam penetration of the simulator vessel. The ratio of 2:1 (between the 40-in. penetration lens and the 20-in. mixer output) produced the change in the angular subtense of the lens necessary to achieve the increased intensity over the smaller diameter that was anticipated and desired (Fig. 2).

Detailed investigation and analysis of the new system, using computer-plotted ray-tracing techniques, has finally evolved a two-part system: a mixer assembly as the optical integrator and a variable section composed of four separate lenses. Each element of this second section is shaped to optimize uniformity of the projected, variable diameter beam. The center two elements are movable (remotely or manually) to vary the beam diameter by a factor of 2 with the resultant intensity increase desired (Fig. 3).

Any reasonable 2:1 diameter ratio (i.e., 20/10, 16/8, 12/6, etc.) can be produced by simple changes of the mixer elements only, utilizing the same variable optical elements for the 2:1 diameter ratio control. The system further provides a real secondary image where aperture controls may be installed should it be desirable to shape the beam for any special test requirement.

[1]Under contract with Optical Research Associates, Pasadena, Calif.

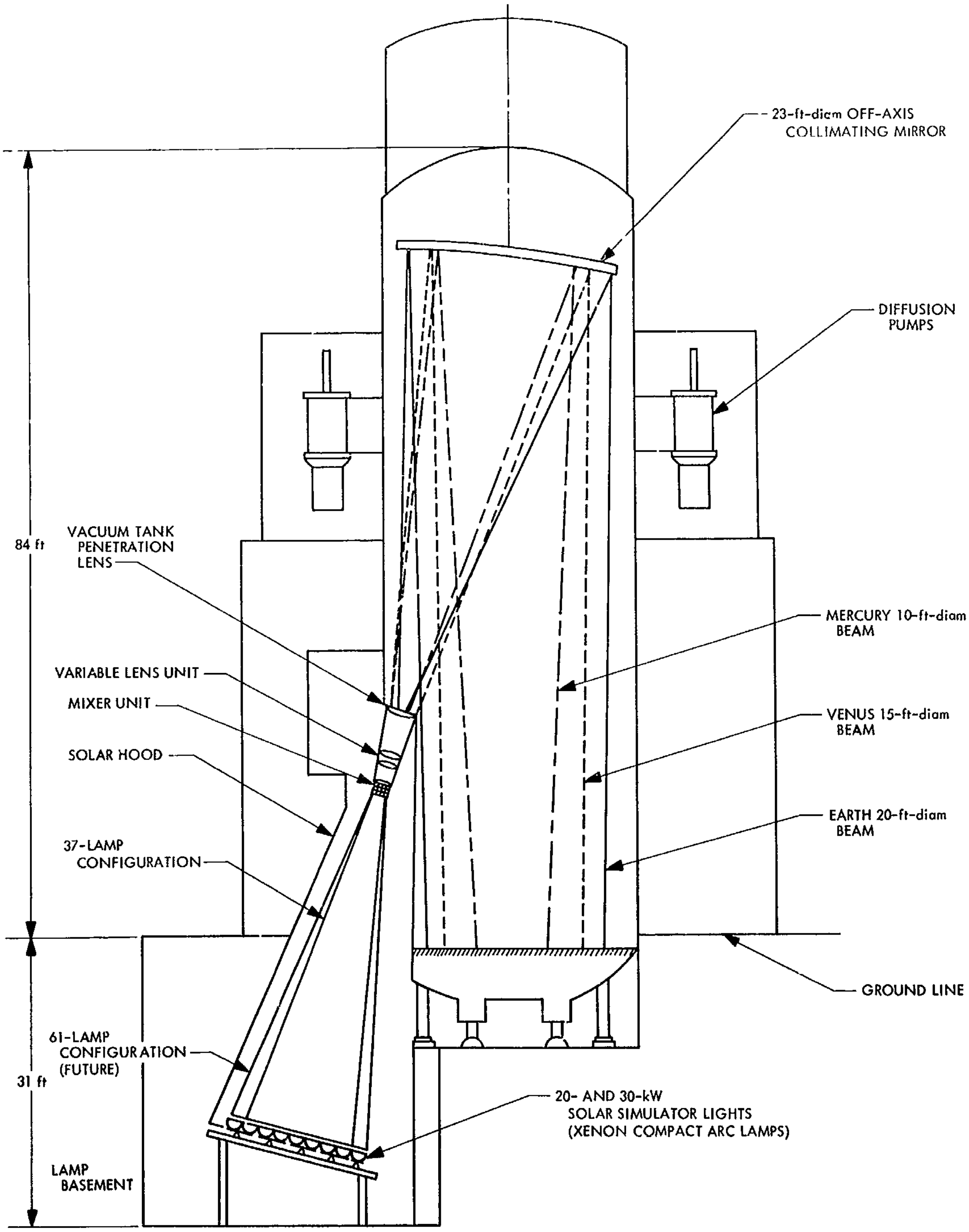


Fig. 2. Simulation capability of 25-ft space simulator with variable optics

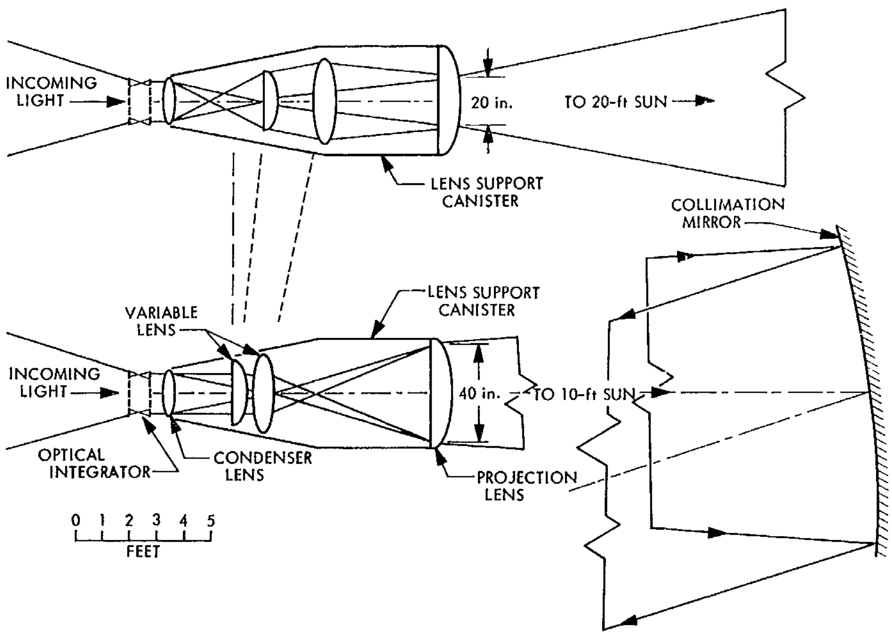


Fig. 3. Variable optics for solar simulator

4. Performance

The optical systems described are capable of the following performance:

Number of Lamps	Mercury intensity 900 W/ft^2		Venus intensity 270 W/ft^2		Uniformity, %
	Diameter, ft	Collimation, deg	Diameter, ft	Collimation, deg	
61	10.0	± 1.9	20.0	± 1	± 3 or less
37	7.8	± 1.9	15.6	± 1	± 3 or less
19	5.6	± 1.9	11.2	± 1	± 3 or less

The 19- and 37-lamp systems are within the present lamp/electrical power limit for the facility, and would not entail any mechanical changes to the basic facility. The 61-lamp system requires the addition of 24 new 30-kW lamps and reflectors as well as the optical modifications. It is clear, from the design of the system, that any intensity level from maximum to zero, is available at any diameter by simply turning off bulbs or reducing their power level. Any intermediate diameter is also available if desired.

The efficiency of the present system very closely approaches 50% (ratio of beam energy to energy projected onto mixer face). Spectral calculations of absorptance, utilization of single layer lens coatings, and considerations of the spectral output of the xenon lamps all combine to project about a 20% loss of energy in the beam over that originally transmitted due to the additional lenses. This represents about 10% of the input energy to the system and can be more than offset by operation of new style bulbs at 25 kW. The selective infrared absorptance of the several lenses reduces the operating temperature of the penetration lens over the present system, thus permitting more optimum sealing. The lens shape (plano-convex) also contributes to the strength of the penetration lens over the current essentially plane window, even though the diameter is doubled.

Reference

1. Bartera, R. E., and Barnett, R. M., *Development of the Jet Propulsion Laboratory Solar Simulator, Type A*, Technical Report 32-638. Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1964.